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MARS BASE BUILDUP SCENARIOS

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ABSTRACT

Two surface base build-up scenarios are presented in order to help visualize the mission and to serve as a basis for trade studies. In the first scenario, direct manned landings on the Martian surface occur early in the missions and scientific investigation is the main driver and rationale. In the second scenario, early development of an infrastructure to exploite the volatile resources of the Martian moons for economic purposes is emphasized. Scientific exploration of the surface is delayed at first, but once begun develops rapidly aided by the presence of a permanently manned orbital station.

INTRODUCTION

In order to place the manned Mars mission (MMM) studies on a more firm conceptual base, we believe that it is helpful to establish one or more specific mission scenarios. This makes it possible to more clearly visualize the context of the overall mission. Base build-up scenarios can serve as a consistent basis for back calculation (e.g., propulsion requirements) and form a common ground for trade studies, costing, etc. The two evolutionary scenarios we propose are two, by necessity, somewhat arbitrary cases selected from a potentially large set of reasonable alternatives. Nevertheless, we believe they perhaps represent "end member" cases that emphasize national political and basic science goals on the one hand versus operational and economic motivations on the other. The scenarios arbitrarily extend over five manned missions and twenty years from the start date. These numbers could easily be extended by factors of two or more but with, in our opinion, considerable less impact and likelyhood of sustained funding. On the other hand, it seems unlikely that anything less than three manned missions could achieve the ambitious overall goals.

COLUMBUS BASE SCENARIO

Objective

The overall objective of this scenario is to establish a manned outpost on the surface of Mars to serve as a base for the scientific exploration of the planet.

Time-line

The missions begin with an unmanned precursor approximately four years before the first manned landing on the Martian surface (the individual missions are discussed in detail below). It is assumed that mission opportunities occur approximately every 2 years. The first three landings are spaced 4 years (2 opportunities) apart and are essentially identical explorations of three sites on the planet (designated sites A. B, and C, Table I). The fourth landing two years later returns to one of the previous landing sites that has been selected as the site at which to begin establishment of the permanent base. Two years later the fifth mission lands an expanded crew to complete construction of the base. When a portion of the crew of the fifth mission leaves some months later, a hold-over crew is left on Mars until relief at the next opportunity. This ends the first phase of the exploration of Mars and assumes a second phase (not discussed) that continues and expands permanent human occupation of the planet.

Unmanned precursor mission

The purpose of an unmanned precursor mission is to obtain information about potential landing sites that will reduce the risk of the first manned landing, position essential assets in the Martian vicinity for future missions, and determine the feasibility of processing resources contained within the Martian moons. These important operational objectives will, as a matter of course, be supplemented by a considerable increase in basic scientific knowledge about Mars and it's moons.

We envision the spacecraft to position a satellite in a low, high inclination orbit from which visual imagery of the surface will be acquired with a per pixel resolution of about one meter. This would allow discrimination of boulders down to a dimension of about three meters, the smallest size object likely to represent a serious landing hazard. Resolution of Viking imagery is about ten meters at best at a small number of sites (fig. 1) and is more like 100 meters or more over most of the planet. If the Viking data is the best that we have as the basis for picking landing sites (the Mars Observer is not planned to include high resolution imagery), the first landing crew could well encounter house-size hazards too exstensively distributed to be evaded using the few kilometer lateral hovering capability of a landing craft. This possiblity seems like an unnecessary risk to us. It is true that the first crew could scrutinize the surface from orbit and select a landing site at that time, but we argue that it would be safer and more productive to extensively preplan and prioritize a number (say, ten) landing sites on the basis of high resolution images and then have the crew validate and possibly reprioritize these sites based on orbital observation.

We propose that the mission also install a very high data rate (laser) communication satellite in mars orbit to transmit the large amount of data required by the high resolution imagery. This comsat should be designed for a long operational life so that it can be used by all of the subsequent manned missions. It is highly likely, in our opinion, that TV coverage of the the manned missions will be a required feature and this plus the large amount of scientific and operational data transmission will necessitate an optical band width communication capability.

Finally, it is possible that the Martian moons Phobos and Deimos contain relatively large amount of water and carbonaceous materials [1]. If so, these materials represent important resources that could be processed for use by the missions. For example, rocket propellant or life support consumables could be manufactured to lessen the amounts needed to be transported from Earth with potentially very large savings. This possibility and it's economic exploitation forms the basis of the second scenario presented below. Consequently, we propose that the precursor mission also rendezvous with one or both of the moons and determine with certainty their compositions.

First landings

As noted above, we propose that the first three manned landings be at three different sites preselected using the precursor results and validated upon arrival in Mars orbit. The sites will be selected on the basis of a balance of scientific and operational criteria. For example, a landing on Tharsis or even Olympus Mons would be exciting and valuable from a scientific viewpoint, but the thinness of the already tenuous Martian atmosphere would probably preclude in situ propellant or water production (ISPP, ISWP) and increase the severity of solar flare irradiation. Thus, some compromise will be established after extensive analysis of all mission goals.

We envision a crew size of six, four of whom will land on the Mars surface and two remain in orbit. The total time in Mars vicinity will be about three months with crew on the surface for about two of those months. The orbital crew will monitor and support the surface activities, perform orbital scientific investigations of Mars, and visit and investigate the Martian moons with probable installation of pilot processing plants there. The prime goal of the surface crew will be to intensively investigate the immediate vicinity of the landing site with the aid of an EVA-type rover vehicle similar to the Apollo LEM. Detailed proposals for surface science investigations are presented elsewhere [2]. An important operational as well as scientific goal will certainly be to determine the presence or absence of water within the Martian surface materials down to depths of several kilometers. The presence of exploitable quantities of water will be a prime selection factor for siting of the permanent base, and it is presumed that with three different landing sites there is a reasonable likelyhood of success in attaining this important goal.

In addition to the scientific investigations, the crew will establish important operational assests and carry out investigations in addition to the water evaluation. The crew will construct a radiation shelter, probably using explosive tunnel driving techniques [3], after first performing some excavation and basic rock mechanics tests. Tests will be performed to evaluate in situ propellant and water production techniques with actual small scale production on the second or third landings if possible. Tests will be performed to evaluate the possibility of growing plants for human consumption since it will be desirable to gain as much self sufficiency as possible by the time the permanent outpost is established.

The surface crew will return scientific samples and data plus operational data and experience, and leave behind a radiation shelter, rover, scientific equipment, and possible propellant and water manufacturing facilities to form the start of a permanent base (if the site is selected) or a "line shack" if the site is revisited later for scientific purposes

Establishing the base

On the fourth manned mission, an expanded crew of twelve will land at one of the previously visited sites to begin construction of a permanent base and to expand the scientific exploration in the vicinity of the base. A second EVA-type rover will be landed that is specially designed for "earth" moving activities. This will be used to expand the surface facilities at the base. The originally constructed radiation shelter will be expanded and modified for permanent habitation. A test enclosure will be constructed to further evaluate agricultural techniques. Sustained production of fuels and water will begin and inventories accumulated.

Scientific exploration of the region around the base will expand and become more sophisticated with the aid of a shirt-sleeve roving vehicle with a range of about 100km [2]. In addition, long range geophysical and meteorlogical investigations will be aided by deployment of a remotely piloted airplane [4] that has a range of several thousand kilometers.

Columbus Base

The fifth landing will occur at the new base some twelve years after the initial manned landing on the surface. Fifteen people will land along with additional vehicles, equipment, supplies, and by this time if not before, a nuclear power plant. Habitats will be expanded along with ISPP, ISWP, and food production. The new vehicles will use ISPP and the old vehicles will be modified to do so. A new, long range vehicle will be introduced that can reach any point on the planet with men and equipment. This will be something like a manned scout rock or air vehicle.

At this point, about a third of the crew will return to Earth and the rest will stay over until relieved by a resupply ship at the next opportunity. The permanent scientific exploration and exploitation of Mars will then begin.

PHOBOS STATION SCENARIO

An alternative approach to direct Martian surface exploration instead emphasizes development of Mars orbital infrastructure before extensive surface activities are attempted. We call this approach the "Phobos Station" scenario. The idea behind this approach is that the Martian moons may contain very valuable resources whose exploitation will be the driver for missions to Mars based on a largely economic rationale as opposed, or in addition, to scientific and political reasons[5]. If the suggested carbonaceous chondrite compositions of Phobos and Deimos are correct, then they may contain as much as 10^{15}kg of water[6] plus large amounts of other volatile elements such as C, N, and alkali metals. All of these volatile elements are rare on the moon but essential ingredients of future large-scale space industrial activities. Furthermore, delivering these valuable resources to the Moon or lunar orbit is only half as expensive, in delta-V terms, as supply from Earth[7] which is the main alternative source besides Earth-crossing asteroids. The latter do not appear to have any advantages over the Martian moons as sources of volatiles for near-Earth space industrial activities. Therefore, we believe that these facts may form the basis of an economic rationale for manned Mars missions that are equally, if not more, compelling than scientific curiosity.

Objective

The overall objective of this scenario is the establishment of the infrastructure to support the economic development of Phobos/Deimos resources. This Mars-orbital infrastructure would then be a way-station for manned scientific exploration of the Martian surface.

Time-line

The missions begin with an unmanned precursor to Mars orbit similar to that proposed in the Columbus Base scenario (Table II). However, in this case the emphasis will be placed on observation and sampling of the Martian moons with essentially no activities aimed at the Martian surface. Two years later, the first manned mission to Mars vicinity will be launched. This mission will have as it's goals the detailed scientific investigation and resource assessment of the Martian moons, and the establishment of pilot ISPP and ISWP plants on or near Phobos. Two years after this, an unmanned mission will be launched to position near Phobos the structural and support elements of a permanent, artificial gravity, mining and refining station. At the next opportunity, the station crew will be sent to assemble and begin operation of the station. Volatiles mining and ISPP production will then be established and expanded over the next few years with crew rotations and resupply at each opportunity. By year +8 or +10 we expect that a substantial, essentially routine, unmanned tanker traffic would be established from Phobos Station to lunar space or surface and thence to LEO. However, before then, probably by +6, the infrastructure would be in place at Phobos Station from which to launch the first Mars surface explorations. With the aid of Phobos Station, the surface exploration could develop at a more rapid pace than with the Columbus Base approach, probably by means of unmanned, teleoperated roving vehicles. By +12 (the same time as for the Columbus Base scenario) it should be possible to establish a permanent manned base on the Martian surface from which to explore the planet. From then on, exploration and development should proceed similarly although the added benefit of the Phobos Base facilities and resources would seem to offer an advantage for continued development compared to the direct, Mars-surface-first approach.

Establishing a manned orbital station

We will not discuss in detail the unmanned precursor or manned surface landings. These should be similar to those proposed for the Columbus Base scenario and any differences can be seen in Table II. Instead, we focus on the one element that is decidedly different in this approach - the manned, artificial gravity, Mars orbital station. We can not give much detail here, but list some requirements such a structure should have. We envision the station as a rotating structure approximately 600m in diameter providing about 1/3 g at 1RPM. This gravity value is chosen to be similar to that of the Martian surface so that crew adapted to the station would also be adapted to Mars. Initially, the station should adequately house about 6 people and be expandable to a crew two or three times that amount. The primary function of the station will be to provide a habitat for personnell engaged in operating the mining and refining operations on Phobos and, eventually, Deimos.

Secondarily, the station will function as a research station for remote investigation of the Martian surface and as a staging base for manned expeditions to the surface. We expect that teleoperation of vehicles and facilities on the Martian surface will be quite effective and will strongly supplement, but not completely replace, manned operations on the surface.

SUMMARY

We have outlined two approaches to the establishment of a permanent manned base on the Martian surface. If achieving scientific and political (i.e., being the first to land men on Mars) goals are paramount, then the direct mission scenario we call "Columbus Base" (or something similar to it) seems to be the most logical. If, driven by space industrialization in the 21st century, the economic demand for the extensive volatile element resources probably contained in the Martian moons becomes as strong as we think it will, then the second scenario we propose looks more robust. In this "Phobos Station" approach, manned exploration of the Martian surface is delayed somewhat in order to develop the infrastructure needed to exploit the Martian moon resources. However, once surface landings and scientific investigations begin, they appear to do so from a much stronger infrastructure base and thus this may be the more powerful and fruitful approach in the long run.

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COLUMBUS BASE SCENARIO

YEAR	-4	0 (start date + 8)	+4	+8	+10	+12
MISSION	precursor	1st Landing	2nd Landing	3rd Landing	4th Landing	5th Landing
CREW (total/land/stay)	UNMANNED	6/4/0	6/4/0	6/4/0	12/12/0	15/15/10
LANDING SITE	orbital	A	B	C	one of A, B, or C (BASE)	COLUMBUS BASE
MARS OPTICAL COMSAT	*	*	*	*	*	*
EVA ROVER (10 km range)		*	*	*	earth-mover	agritractor
SHIRT-SLEEVE ROVER (100 km range, the "Winnebago")					*	*
RPV (mars airplane)					*	* (uses ISPP)
MANNED SCOUT ROCKET (uses ISPP, 20,000 km range)						*
ISPP		Test/PP	Test/PP	Test/PP	PRODUCTION	[illegible]ication & PRODUCTION
ISWP		Test/PP	Test/PP	Test/PP	PRODUCTION	Modification & PRODUCTION
PERMANENT SHELTER		Test/RS	RS	RS	HAB PRODUCTION	HABITAT
AGRICULTURE		Test	Test	Test	Test Enclosure	PRODUCTION
SSTS NETWORK (#/dimension)		4/5 km	4/5 km	4/5 km	20/30 km	50/10,000 km

ISPP = In situ propellant production.
ISWP = In situ water production.
SSTS = Surface science telemeter station (station number/network dimension).
PP = Pilot production.
RS = Radiation shelter.

PHOBOS STATION SCENARIO

YEAR	-2	0 (start date + 8)	+2	+4	+6 to +10	+12
MISSION	precursor	Ph/D landing	precursor	PHOBOS STATION	1st Surface Landings	Surface base
CREW (total/land/stay)	UNMANNED	6/4/0	UNMANNED	6/0/6	12/4/0	15/15/10[c]
LANDING SITE	orbital	Ph/D		PERMANENT ORBITAL STATION	multiple sites plus teleoperated vehicles from Phobos Station	SURFACE BASE
MARS OPTICAL COMSAT	*	*	*	*	*	*
EVA ROVER (10 km range)					*	additional vehicles
SHIRT-SLEEVE ROVER (100 km range, the "Winnebago")					*	*
RPV (mars airplane)					*	* (uses ISPP)
MANNED SCOUT ROCKET (uses ISPP, 20,000 km range)						*
ISPP		Test/PP[a]		PRODUCTION	PRODUCTION[d] AND EXPORT	SURFACE PRODUCTION
ISWP		Test/PP[a]		PRODUCTION	PRODUCTION AND EXPORT	SURFACE PRODUCTION
PERMANENT SHELTER			Station Elements		RS	HABITAT
AGRICULTURE		Test[b]		PP	Test Enclosure	PRODUCTION
SSTS NETWORK (#/dimension)					4/5 km	50/10,000 km

ISPP = In situ propellant production.
ISWP = In situ water production.
SSTS = Surface science telemeter station (station number/network dimension).
PP = Pilot production.
RS = Radiation shelter.

(a) On Phobos.
(b) On spacecraft using Phobos resources.
(c) Permanently manned surface base, may exchange crew with Phobos Station.
(d) Production for export to lunar space, and LEO with logistic support for surface landings.